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Joshua trees (*Yucca brevifolia*) (photo P. Gonzalez)

Anthropogenic Climate Change in Joshua Tree National Park, California, USA

Patrick Gonzalez, Ph.D.

U.S. National Park Service
Natural Resource Stewardship and Science

University of California, Berkeley
Department of Environmental Science, Policy, and Management
Institute for Parks, People, and Biodiversity

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Abstract

Greenhouse gas emissions from cars, power plants, and other human sources have caused anthropogenic climate change and impacts on ecosystems and human well-being. To assist in the integration of climate change science into resource management in Joshua Tree National Park, California, this report presents results on climate trends, historical impacts, future risks, and carbon in the park. Spatial analyses of historical climate data at 800 meter spatial resolution show that annual average temperature of the area within park boundaries increased at a statistically significant rate of 1.5 ± 0.1ºC (2.7 ± 0.2ºF.) per century (mean ± standard error) from 1895 to 2016. During that period, total annual precipitation decreased at a statistically significant rate of -32 ± 12% per century. A scientific literature review shows that field research in the region that included measurements in the park has detected two historical changes attributed to anthropogenic climate change: a loss of 43% of bird species across the Mojave Desert between the periods 1908-1968 and 2013-2016 and a 30 ± 17 km northward shift of winter bird ranges across the lower 48 US states from 1975 to 2004. The mortality of 80% of a sample of Joshua trees (*Yucca brevifolia*) from burning in the 1999 Juniper Fire and 26% of unburned trees due to drought was consistent with, but not directly attributed to climate change. Under the highest greenhouse gas emissions scenario of the Intergovernmental Panel on Climate Change (Representative Concentration Pathway [RCP] 8.5), thirty-three climate models project an increase in annual average temperature of the park of 4.6 ± 0.9ºC (8.3 ± 1.6ºF.) from 2000 to 2100. Cutting emissions from human activities (RCP2.6) to meet the Paris Agreement goal could reduce projected heating by two-thirds. Approximately half the models project increased precipitation and half project decreases, although higher temperatures would tend to increase aridity. Four published analyses indicate that, if aridity increases, climate change under the highest emissions scenario could nearly eliminate suitable habitat for Joshua trees from Joshua Tree National Park and reduce habitat across the southwestern US 90% by 2100. Lower emissions (RCP4.5) could limit the loss to ~80%. Other future risks from increased aridity include possible loss of habitat for the desert tortoise (*Gopherus agassizii*) and other wildlife. If rainfall or extreme storms increase, invasive grasses could increase, providing fuel for more wildfire. Vegetation in the park helps reduce climate change by storing 140 000 ± 200 000 tons of carbon. Motor vehicles of staff and visitors generate 80% of the 1800 tons per year of park emissions, pointing to ways to help reduce the cause of climate change.

Introduction

Greenhouse gas emissions from cars, power plants, deforestation, and other human activities have caused climate change (IPCC 2013, USGCRP 2017). Field research shows that human-caused climate change is altering ecosystems and affecting the well-being of people by melting glaciers, raising sea level, aggravating wildfire, increasing tree death, contributing to animal extinctions, and causing other impacts globally (IPCC 2014), across the United States (USGCRP 2018), and in United States national parks (Gonzalez 2017).

In response, national parks are developing resource management strategies for conservation under climate change. To assist in the integration of climate change science into resource management in Joshua Tree National Park (Figure 1), this report presents results of spatial analyses of historical and projected climate trends and an assessment of published scientific research on historical impacts of climate change, future risks, and carbon.

Methods

Historical climate This report presents results of spatial analyses of historical climate trends (Gonzalez et al. 2018) from previously published climate data layers at a spatial resolution of 800 meters, derived from point weather station measurements using the Parameter-elevation Relationships on Independent Slopes Model (PRISM; Daly et al. 2008). PRISM uses elevation and topography to interpolate climate values in the spaces among weather stations. This report summarizes results by giving trends for the area within park boundaries as a whole and maps of the spatial patterns of climate trends across the park and surrounding area.

Linear regression of temperature and precipitation time series gives the historical climate trends, with the statistical probability of significance corrected for temporal autocorrelation. Analyses of monthly, seasonal, and annual climate were originally run for the periods 1895-2010 and 1950-2010, the data available at the time of the original research. Additional analyses of annual trends were later run for the period 1895-2016. The time periods starting in 1895 provide the longest available weather station-based trends for the area of the park, but the configuration of the US weather station network stabilized in the 1950s (Vose et al. 2014), so the period starting in 1950 gives a trend based on a more consistent set of stations. The report also presents the annual trends for the period 1936-2017 at the National Weather Service weather station in the city of Twentynine Palms, next to the park (https://www.ncdc.noaa.gov/cdo-web/datasets/GSOM/stations/GHCND:USC00049099/detail).

Projected climate This report presents spatial analyses of future projections of climate (Gonzalez et al. 2018) that use output of all available general circulation models (GCMs) in the Coupled Model Intercomparison Project Phase 5 dataset developed for the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC 2013). The coarse-scale GCM output, at spatial resolutions of up to 200 km, has been downscaled to 800 m spatial resolution using the bias correction and spatial disaggregation method (Wood et al. 2004) and the PRISM historical climate time series as a base layer (Daly et al. 2008). Future projected changes are expressed as the change from the standard 1971-2000 historical baseline.

IPCC has coordinated research groups to project possible future climates under four defined greenhouse gas emissions scenarios, called representative concentration pathways (RCPs; Moss et al. 2010). The four emissions scenarios are RCP2.6 (reduced emissions from energy efficiency and of renewable energy, achieving the goals of the Paris Agreement (UNFCCC 2015), RCP4.5 (low emissions), RCP6.0 (high emissions, somewhat lower than continued current practices), and RCP8.5 (highest emissions, no emissions reductions). Climate under each of the four scenarios was projected by up to 33 GCMs. The four emissions scenarios determine the overall range of potential futures. Within each scenario, the spread of projections of the GCMs generates a range of potential futures, characterized here by the average and standard deviation of the GCM ensemble for each scenario.

Historical impacts and future risks This report also assesses information on historical impacts of climate change, future vulnerabilities, and carbon. The impacts and vulnerability information come from a search of the Clarivate Analytics Web of Science, the authoritative database of scientific literature, for published research that used field data from Joshua Tree National Park and the surrounding region.

Carbon Ecosystem carbon data come from a previously published statewide analysis of remote sensing and field data (Gonzalez et al. 2015). Analyses of Landsat remote sensing and field measurements of biomass across the state of California produced estimates of the carbon in aboveground vegetation for the grasslands, woodlands, forests, and other non-agricultural and non-urban areas of the state at 30 m spatial resolution (Gonzalez et al. 2015). Monte Carlo analyses of error in tree measurements, remote sensing, and the carbon fraction of biomass quantified the uncertainty of carbon stock change estimates. Validation of the carbon stock estimates by independent stock estimates derived from measurements at field sites found that the new results were close to field-derived estimates (Gonzalez et al. 2015).

Historical Climate Trends

Temperature Average annual temperature increased at a statistically significant rate of 1.5 ± 0.1ºC (2.7 ± 0.2ºF.) per century (mean ± standard error) from 1895 to 2016 for the area within park boundaries (Figure 2, Table 1) (Gonzalez et al. 2018). The total change from 1895 to 2016 was 1.8 ± 0.2ºC (3.2 ± 0.4ºF.) Average annual temperature increased more rapidly at the Twentynine Palms weather station, at a statistically significant rate of 2.3 ± 0.4ºC (4.1 ± 0.7ºF.) per century from 1936 to 2017 (Figure 2).

Seasonally, temperatures in the park increased at the highest rate in spring (Figure 3, Table 1). Temperatures for the period 1895-2010 increased at statistically significant rates in all four seasons and nine of 12 months. Between 1895 and 2010, the part of the year with an average monthly temperature above 27ºC (81°F.) increased from zero to approximately six weeks (Figure 3).

Spatially, temperature increases were highest in the eastern parts of the park, in the Pinto Basin, east of the Ocotillo Patch, and in the Coxcomb Mountains (Figure 4).

Precipitation Total annual precipitation decreased at a statistically significant rate of -32 ± 12% per century from 1895 to 2016 for the area within park boundaries (Figure 5) (Gonzalez et al. 2018). The total change from 1895 to 2016 was -39 ± 15%. Annual, seasonal, and monthly precipitation changes for the periods 1895-2010 and 1950-2010 were not statistically significant (Table 2). At the Twentynine Palms weather station, total annual precipitation decreased from 1936 to 2017, but the trend was not statistically significant.

Spatially, the more severe rainfall declines in the period 1895-2016 occurred in central and western parts of the park, including Wilson Canyon, Forthynine Palms Oasis, Indian Cove, and along Park Boulevard (Figure 6).

For the southwestern US as a whole, extreme storms have increased in the past half-century, with the amount of precipitation in 20-year events (a day with more precipitation than any other day in 20 years) increasing in all four seasons from 1948 to 2015, attributable in part to anthropogenic climate change (Easterling et al. 2017).

Drought A severe drought struck most of California, including the region around Joshua Tree, from 2012 to 2016, with, from 2012 to 2014, the lowest 12-month precipitation total combining with the hottest annual average temperature in the period 1896-2014 (Diffenbaugh et al. 2015). Analyses of the Palmer Drought Severity Index (PDSI), an indicator of near-surface soil moisture, for the period 1901-2014 indicate that 2014 was the driest year in the record for much of the state, and the 11^{th} to 30^{th} driest year in the region around Joshua Tree (Williams et al. 2015). The change in climate water deficit, the difference between potential and actual evapotranspiration, between the periods 1900-1939 and 1970-2009 was 10 to 25 mm in the region around Joshua Tree, indicating that the area became more arid (Rapacciuolo et al. 2014).

Analyses of PDSI for the period 1896-2014 showed that, while the probability of low precipitation years has not increased, the hotter temperatures caused by human-caused climate change have increased the probability of drought by increasing the probability of high temperature and low precipitation occurring at the same time (Diffenbaugh et al. 2015). For the State of California as a whole, the high temperatures of anthropogenic climate change accounted for one-tenth to one-fifth of the 2012-2014 period of the drought (Williams et al. 2015).

Historical Impacts

Changes detected in the region and attributed to anthropogenic climate change

Published research that includes data from Joshua Tree National Park and southern California has detected two changes that are statistically significantly different from natural variation and has attributed the cause of the changes to anthropogenic climate change more than other factors.

Bird species decline Field surveys from 2013 to 2016 at 61 sites in the Mojave Desert, including 13 sites in Joshua Tree National Park and sites in Death Valley National Park and Mojave National Preserve, counted birds at sites originally surveyed by University of California, Berkeley, biologist Joseph Grinell and colleagues from 1908 to 1968 (Iknayan and Beissinger 2018). The research detected an average loss of 43% of bird species. Analyses of potential causal factors, including climate, fire, and grazing, attributed the loss to reduced precipitation caused by anthropogenic climate change. Thirty-eight of the thirty-nine species that showed a statistically significant decrease in occupancy are listed by the National Park Service (NPS) Inventory and Monitoring Program as present in the park (NPS 2019), including, for example, the canyon wren (*Catherpes mexicanus*), Costa's hummingbird (*Calypte costae*), Lawrence's goldfinch (*Spinus lawrencei*), western bluebird (*Sialia mexicana*), and the white-throated swift (*Aeronautes saxatalis*). Only one species showed a statistically significant increase in occupancy, the common raven (*Corvus corax*), listed as present in the park.

Bird range shifts Analyses of Audubon Christmas Bird Count data across the US, including the count in the park, detected a 30 ± 17 km northward shift of the winter center of abundance of a set of 254 bird species across the lower 48 US states from 1975 to 2004, attributable more to anthropogenic climate change than other factors (La Sorte and Thompson 2007). For example, the canyon wren (*Catherpes mexicanus*), one of the species shifting north and a species listed as present in the park (NPS 2019), has shown a statistically significant reduction of 79 ± 33% of sightings per observer-hour in the park count. Additional analyses found northward shifts across the US from 1975 to 2011 of winter distributions of six raptor species listed as present in the park: American kestrel (*Falco sparverius*), golden eagle (*Aquila chrysaetos*), northern harrier (*Circus cyaneus*), prairie falcon (*Falco mexicanus*), red-tailed hawk (*Buteo jamaicensis*), and rough-legged hawk (*Buteo lagopus*) (Paprocki et al. 2014).

Changes consistent with, but not formally attributed to human-caused climate change

Other research has found changes consistent with human-caused climate change, but either has not detected changes that are statistically significantly different than historical variability or has not analyzed potential causal factors to formally attribute the cause of the change.

Joshua tree mortality Field surveys of Joshua trees (*Yucca brevifolia*) at five pairs of sites from 2000 to 2004, following the May 1999 Juniper Fire, found that 80% of burned trees and 26% of unburned trees died (DeFalco et al. 2010). Fire damage, the aridity of below-average rainfall in 1999 and 2002, and gnawing by pocket gophers (*Thomomys bottae*) killed the trees. In addition, analyses of MODIS remote sensing data found reductions of vegetation cover of up to 50% from 2001 to 2010 in the Juniper Fire burn area and other western parts of the park (Munson et al. 2016). An increase in Joshua tree mortality and in the invasive grasses that fueled the fire are consistent with the increased heat, atmospheric carbon dioxide, and extreme rainstorms of climate change. The time series, however, were too short to detect a statistically significant long-term increase in mortality or to examine causal factors for direct attribution to climate change. The park does not yet have a long-term time series of Joshua tree densities which would be necessary to draw robust conclusions on detection of changes and attribution of causes.

Sonoran desert plant mortality Field surveys of a site in the bajada of the Eagle Mountains from 1984 to 2004 found mortality of 55 to 100% of six of the most common perennial plants following a drought in 2002 (Miriti et al. 2007). Desert mallow (*Sphaeralcea ambigua*) disappeared from the site. The other species that substantially declined were burro weed (*Ambrosia dumosa*), California buckwheat (*Eriogonum fasciculatum*), pencil cholla (*Cylindropuntia ramosissima*), jojoba (*Simmondsia chinensis*), and Hall's purple bush (*Tetracoccus hallii*). This substantial death of Sonoran desert plants is consistent with the increased heat of climate change, but an analysis of causal factors was not conducted to directly attribute the episode to climate change.

Wildfire increase in western deserts Burned area in the Sonoran and Mojave Deserts showed statistically significant increases of six orders of magnitude (1 million-fold increase) from 1970 to 2010 (Syphard et al. 2017a). This is consistent with the increased heat of climate change in the region. Analyses of causal factors, however, indicate that human ignitions and the spread of invasive annual plant species, caused mainly by human introductions, are more important than climate change in explaining the increase (Syphard et al. 2017a, 2017b). In the mid-elevation shrublands of the Mojave Desert, human-ignited fires accounted for half of burned area from 1980 to 2004 (Brooks and Matchett 2006).

Desert tortoise mortality Monitoring of the abundance of the desert tortoise (*Gopherus agassizii*), listed as threatened under the U.S. Endangered Species Act, in a 2.6 km^2 plot in the eastern part of the park found that the population declined by approximately 90% from 1993 to 2012 (Lovich et al. 2014). Extremely dry years in 1996, 1997, 1999, and 2000 seemed to cause the increase in tortoise deaths. This is consistent with the increased heat of climate change but the time series was too short to draw a robust conclusion about a long-term trend or to examine causal factors for direct attribution to climate change.

Future Climate Projections

Temperature Under the highest emissions scenario (RCP8.5), average annual temperature of the area within park boundaries would increase 4.6 ± 0.9ºC (8.3 ± 1.6ºF.) by 2100 (Figure 7, Table 3), compared to the 1971-2000 baseline (Gonzalez et al. 2018, IPCC 2013). Cutting greenhouse gas emissions from human activities (emissions scenario RCP2.6) could reduce projected heating by two-thirds. GCMs project the highest temperature increases in summer (Table 3). Under the highest emissions scenario, climate change could lengthen the period of temperatures above 28ºC (82ºF.) from zero to three months by 2100 (Figure 3). Cutting carbon emissions from human activities could reduce the increase in the warm period by two-thirds.

Spatially, projected temperature increases are similar across the park, increasing slightly with increasing distance from the Pacific coast (Figure 8).

For the region around the park, GCMs project an increase of 30 to 40 more days per year with a maximum temperature >32ºC (90ºF.) from 1990 to 2050 under the highest emissions scenario

(RCP8.5) (Vose et al. 2017). GCMs also project an increase of 2 to 3ºC (4 to 6ºF.) in the hottest temperature of the year by 2050 under RCP8.5 (Vose et al. 2017).

Precipitation For the area within park boundaries, approximately half of the GCMs project increases and half project decreases (Figure 7). This lack of agreement exists for monthly, seasonal, and annual projections (Table 4). The average of all of the models is a slight increase, although it is not statistically significant. Projections indicate a tendency for decreased rainfall in the spring. Even if precipitation increases, increasing temperatures would tend to increase aridity in many cases through an increase in evapotranspiration (Thorne et al. 2015). Spatially, projected precipitation changes are similar across the park (Figure 9).

GCMs project increases in extreme storms for the region. For the Southwest US as a whole, models project an increase in five-year storms (a two-day period with more precipitation than any other two-day period in five years) to once every three years (low emissions scenario, RCP4.5) or every two years (highest emissions scenario, RCP8.5) (Easterling et al. 2017). In addition, models project a 20% increase in the amount of precipitation in 20-year storms (a storm with more precipitation than any other storm in 20 years) under the highest emissions scenario (RCP8.5) (Easterling et al. 2017). Atmospheric rivers, narrow bands of highly concentrated storms in that move from the Pacific Ocean into California (Warner et al. 2015, Wehner et al. 2017), are projected to increase in frequency and intensity (Jeon et al. 2015, Lavers et al. 2015, Hagos et al. 2016, Kossin et al. 2017). The number of days per year with precipitation may decrease, however, leading to intense wet periods alternating with more intense droughts (Polade et al. 2014, 2017).

Drought Hotter temperatures caused by anthropogenic emissions of greenhouse gases have increased the probability of drought in California by increasing the probability of high temperature and low precipitation occurring at the same time (Diffenbaugh et al. 2015). For the State of California as a whole, under the highest emissions scenario (RCP8.5), climate change increases the probability of a drought as severe as the 2012-2016 drought to ~100% by 2030 (Diffenbaugh et al. 2015). For the southwestern US as a whole, under the highest emissions scenario (RCP8.5), the severity of drought by 2100 AD could increase to a level more severe than any since 1000 AD (Cook et al. 2015). Anthropogenic climate change sharply increases the risk of a megadrought, a persistent dry period lasting 10 years or more, with the probability of a megadrought in the region of Joshua Tree increasing to 70-90% under a temperature increase of 4ºC (Ault et al. 2016). GCMs project five to ten more dry days per year in southern California (Polade et al. 2014).

The increased heat of anthropogenic climate change may also cause aridification, a potentially permanent change to a drier environment, across the southwestern US, through increased evapotranspiration (Cook et al. 2014, 2016, Jones and Gutzler 2016) and lower soil moisture (Wehner et al. 2017). Permanent reduction of precipitation could reduce water flow at desert springs (Anderson et al. 2006, Wendt et al. 2018).

Future Risks

Without greenhouse gas emissions reductions from human activities, continued climate change could substantially increase risks of species and ecosystems to increased mortality and other effects (IPCC 2013). Published research using data from Joshua Tree National Park has identified numerous risks of vegetation and wildlife to anthropogenic climate change.

Vegetation

Joshua tree loss of suitable climate Four published analyses show that continued anthropogenic climate change causes a high risk of losing the area of suitable climate for Joshua trees from Joshua Tree National Park (Dole et al. 2003, Cole et al. 2011, Barrows and Murphy-Mariscal 2012, Sweet et al. 2019). While the Joshua tree is adapted to the current climate of the Mojave Desert, intense drought can kill adult trees and inhibit germination and survival of young trees. Under the highest emissions scenario (RCP8.5), climate change could nearly eliminate suitable habitat for Joshua trees from the park by 2099 (Sweet et al. 2019) (Figure 10). Under a scenario of lower emissions (RCP4.5), modeling projects a loss of suitable habitat of ~80%. These results came from a species distribution model that related 1747 field-surveyed occurrences of Joshua trees to spatial data of climate at 270 m spatial resolution, topography, and soil, but the projections used the output of only one GCM, MIROC, which projects hotter and drier conditions for southern California (Underwood et al. 2018). Joshua tree presence was most closely related to total annual precipitation. An analysis of field counts of all

Joshua trees in 14 nine-hectare plots found an average density of 290 trees per hectare, 9% of these juvenile trees. The six plots with juvenile recruitment higher than the average were located in or close to the areas modeled as climate change refugia under low emissions (RCP4.5), which were higher in elevation and lower in temperature. This recent research (Sweet et al. 2019) followed three previous spatial analyses of the future vulnerability of Joshua trees to climate change.

A temperature increase of 3ºC with no change in precipitation could reduce suitable habitat for Joshua trees in the park by 90% (Barrows and Murphy-Mariscal 2012). A lower temperature increase of 1ºC would reduce suitable habitat by one-third. These results came from a species distribution model that projected suitable climate at 800 m spatial resolution under temperature increases of 1º, 2º, and 3ºC and precipitation decreases of 0, -25, -50, and -75 mm. The research did not use IPCC emissions scenarios or GCMs. A temperature increase of 3ºC is similar to the high emissions scenario RCP6.0 while a temperature increase of 1ºC is lower than the reduced emissions scenario RCP2.6.

Under a medium emissions scenario (A1B; IPCC 2001) and under a scenario of a doubling of atmospheric CO_2 (IPCC 2001), climate change could reduce suitable habitat for Joshua trees across the southwestern US by 90% and leave no suitable habitat in Joshua Tree National Park (Cole et al. 2011) (Figure 11). The projections showed potential new areas of suitable climate for the species farther upslope and north, particularly in Nevada, Utah, and Arizona. These results came from a species distribution model that related field-surveyed occurrences of Joshua trees (both *Yucca brevifolia* and the dwarf variety *Yucca brevifolia* var. *jaegeriana*) to climate data at 1 km and 4 km spatial resolution. The 1 km spatial projection used the CO_2 doubling scenario of IPCC (2001), which is similar to the highest emissions scenario RCP8.5 (IPCC 2013), and one GCM. The 4 km spatial projections used the medium emissions scenario (A1B) of IPCC (2007), which is between RCP4.5 and RCP6 (IPCC 2013), with five GCMs and the CO_2 doubling scenario with 22 GCMs.

Under a doubling of atmospheric CO_2, another analysis indicates that climate change could reduce suitable habitat for Joshua trees across the southwestern US by three-quarters and leave only a small refugium in the park (Dole et al. 2003). The projections showed potential new areas of suitable climate for the species farther upslope and north in Nevada. These results came from a statistical analysis that related a species distribution map to climate variables at 10 km spatial resolution. The projection used only one GCM.

Joshua tree climate and reproductive sensitivity Paleobiological data from packrat middens and fossil dung of the extinct Shasta ground sloth (*Nothrotheriops shastensis*) provide information on the climate and reproductive sensitivity of Joshua trees. These paleobiological data show that Joshua trees grew from 13 000 to 22 000 years ago across a wider range than today, extending farther east and south into what is now southern Arizona and possibly into Mexico down to the Gulf of California, 300 km south of the current southern limit of its range in Joshua Tree National Park (Holmgren et al. 2010, Cole et al. 2011). Fossil evidence suggests that a major retraction of the range of the Joshua tree began approximately 11 700 years ago, coinciding with a warming in the Southwest of 4ºC, caused by orbital cycles, that marked the end of the Pleistocene epoch and beginning of the Holocene epoch (Cole et al. 2011). Analyses of the DNA of Joshua trees and four moth pollinators, however, did not show signs of a range retraction in the Holocene (Smith et al. 2011). Still, no fossil evidence of Joshua trees earlier than 8000 years ago have been found south of what is now Joshua Tree National Park (Cole et al. 2011). This suggests a sensitivity of Joshua trees of 300 km latitude per 4ºC.

Furthermore, little northward migration of Joshua trees has occurred in the Holocene, at most one to two meters per year. Fossil evidence shows that the Shasta ground sloth had eaten Joshua tree fruits. The lack of Joshua tree dispersal since the extinction of the Shasta ground sloth 13 000 years ago suggests that the sloth spread the Joshua tree (Cole et al. 2011, Lenz 2001), although contemporary dispersal by mammals and a thin seed that might not survive after being eaten by a sloth are factors against sloth dispersal (Waitman et al. 2012).

Germination tests in Nevada found that seeds germinate best after rainfall in temperatures currently common in spring and summer (Bryant et al. 2012). Surveys of reproduction at 10 sites across the southwestern US in the high bloom year of 2013 found positive correlations between flower and seed production and temperature and a negative correlation of stand density and temperature (St. Clair and Hoines 2018). This suggests sensitivity of establishment to heat. Tracking of a stand of trees at Yucca Flat, Nevada, for 22 years found that herbivory of young Joshua trees by rodents and rabbits increases in drought years (Esque et al. 2015).

Joshua trees are sensitive to fire. The 1999 Juniper Fire immediately killed plants of height <1 m (DeFalco et al. 2010). Experimental growth of Joshua trees under elevated atmospheric CO_2 found increased tolerance to cold temperatures (Loik et al. 2000), which could contribute a slight expansion of its potential range under climate change (Dole et al. 2003).

Surveys of Joshua trees and their two exclusive and obligate pollinators, yucca moths (*Tegeticula synthetica* and *Tegeticula antithetica*) at nine sites in the park and two sites northwest of the park examined reproductive success (Harrower and Gilbert 2018). The surveys showed that larger trees produced more flowers, attracted more pollinators, and achieved higher seed set (number of seeds produced per flower). Seed set and seed predation were highest in the 1200-1400 m elevation range, where both tree density and pollinator abundance were highest. The surveys did not find any Joshua tree germination from seeds at the highest or lowest elevations, suggesting limits to natural capacities for upslope shifting.

Other vegetation loss In addition to the vulnerability of Joshua trees, species distribution modeling indicates that, under a temperature increase of 3ºC, six other species could lose three-quarters or more of their suitable habitat in the park: Acton encelia (*Encelia actoni*), black brush (*Coleogyne ramosissima*), California juniper (*Juniperus californica*), desert ironwood (*Olneya tesota*), desert scrub oak (*Quercus cornelius-mulleri*), and single leaf pinyon (*Pinus monophylla*) (Barrows et al. 2014). Five other species could lose one-seventh to three-quarters of their suitable habitat in the park: brittlebush (*Encelia farinosa*), burro weed (*Ambrosia dumosa*), creosote bush (*Larrea tridentata*), jojoba (*Simmondsia chinensis*), and ocotillo (*Fouquieria splendens*). Potential refugia are generally in the San Bernardino Mountains or other higher elevation areas. Analyses of sites across the Mojave Desert, including Joshua Tree, indicated that site characteristics, including north aspect, high elevation, stream wash, sandy soil, and deep soil, reduce vulnerability of Mojave Desert plant species (Munson et al. 2015).

Invasive plant increase Climate change can favor invasive alien plants in temperate zones, including in the park, for three main reasons:

> **Carbon dioxide (CO_2) enrichment** Invasive alien plants generally exploit atmospheric CO_2 more efficiently than native species, giving them higher growth rates (Davidson et al. 2011, Liu et al. 2017). Carbon enrichment experiments on red brome (*Bromus rubens*), an

invasive alien annual widespread in the park and across the Mojave Desert, indicated that a doubling of atmospheric CO_2 (equivalent to the high emissions scenario, RCP6.0) could lead to a 20% increase in seeds (Huxman et al. 1999) and that a tripling of atmospheric CO_2 (higher than the high emissions scenario, RCP8.5) could increase primary productivity by one-fifth (Yoder et al. 2000).

Warmth and moisture Increasing warmth and moisture due to climate change can increase the suitability of temperate zone ecosystems to plants from tropical zones (Theoharides and Dukes 2007, Hellmann et al. 2008). Any future conditions of increasing aridity would be unfavorable to invasive alien plants that thrive in moister conditions. For example, field studies in the Coachella Valley, south of the park, show that Sahara mustard declines under increasing aridity (Barrows et al. 2009). Conversely, any future conditions of increasing moisture could favor invasive alien plants. The chance of increased frequency of extreme storms in the region (Easterling et al. 2017) could lead to episodes of higher moisture, which, if they would happen, would occur in winter (Table 4). Red brome invasion of native grassland and shrubland communities in the Mojave increases with higher winter rainfall (Brooks and Berry 2006). Species distribution modeling indicates that climate change, under the low emissions scenario (RCP4.5) and the highest emissions scenario (RCP8.5), can increase the abundance of red brome and Sahara mustard in the park, due to higher temperatures and extreme high rainfall events (Curtis and Bradley 2015).

Projected longer growing seasons under climate change would favor invasive alien grasses in the Mojave and Sonoran Deserts (Abatzoglou and Kolden 2011). In addition, with sufficient winter precipitation, nitrogen deposition from automobile air pollution increases red brome growth (Rao and Allen 2010, Rao et al. 2010).

Disturbance Invasive alien plants often proliferate in disturbed sites (Theoharides and Dukes 2007, Hellmann et al. 2008). Anthropogenic climate change causes two disturbances: biome shifts (Gonzalez et al. 2010) and increased wildfire (Littell et al. 2009, Abatzoglou and Williams 2016). These two disturbances from climate change lead to a high risk of invasive alien species in the eastern and northwestern parts of the park (Early et al. 2016). Wildfire, in particular, opens up Mojave shrublands to invasive alien annual grasses (Brooks 1999, Horn and St. Clair 2017). Field surveys of six burned areas in the park showed that invasive alien plant cover quickly returned to pre-burn levels (Vamstad and Rotenberry 2010).

Wildfire increase Under high emissions (scenario A2 of IPCC (2007), higher than RCP6.0 of IPCC (2013)), hotter temperatures may double potential fire frequency by 2050 (Mann et al. 2016) and burned area by 2100 (Westerling et al. 2011) in the western half of the park. Approximately half of the projected area of climate refugia for Joshua trees under low emissions (RCP4.5) burned between 1878 and 2018 (Sweet et al. 2019).

Any increase in wildfire depends, however, on an increase in invasive grass species. Bare soil separates shrubs in undisturbed Mojave ecosystems, leading to low natural incidence of wildfire (Brooks 1999). The invasion of red brome into Mojave shrublands has provided a layer of fine fuels that can carry a fire across the interspaces (Brooks 1999). Consequently, red brome invasion contributed substantially to an increase in fire size in mid-elevation shrublands across the Mojave Desert from 1980 to 2004 (Brooks and Matchett 2006). Analyses of fire ignitions from 1992 to 2011 in Joshua Tree National Park and other protected areas in the Mojave indicates that fire probability is highly related to remotely-sensed herbaceous cover (Hegeman et al. 2014). If precipitation increases under continued climate change, the potential increase of red brome cover may increase fire risk across the Mojave and Sonoran Deserts (Abatzoglou and Kolden 2011). On the other hand, if precipitation or aridity increase under continued climate change, invasive grasses would not tend to increase, causing a lack of fuel for wildfires.

Field research has found that nitrogen deposition, from automobile air pollution, has exceeded critical loadings at two of four sites in the park, increasing growth of grasses and increasing fire risk (Rao et al. 2010). Fields surveys of vegetation at six sites in the park that burned two to 65 years prior to the surveys found that vegetation did not recover to its pre-burn composition (Vamstad and Rotenberry 2010).

Wildlife

Desert tortoise mortality While the desert tortoise (*Gopherus agassizii*) is adapted to an arid environment, it is vulnerable to dying in extreme heat or drought (Lovich et al. 2014). Species distribution modeling indicates that a temperature increase of 3ºC could reduce the area of suitable habitat for the tortoise in the park by four-fifths (Barrows et al. 2014). The combination of the temperature increase and a rainfall decrease of 75 mm per year could lead to a potential loss >90% (Barrows 2011). Limiting the temperature increase to 1ºC and the rainfall decrease to 25 mm per year could keep the loss of suitable habitat to two-thirds (Barrows 2011). Desert tortoises depend on underground cover sites to shelter from extreme heat, with longer tunnels keeping temperatures cooler (Mack et al. 2017). Feeding trials of captive tortoises showed that red brome is poor forage for the tortoise, so any increase in red brome due to climate change can reduce fitness for the tortoise (Drake et al. 2016).

Other Reptiles Species distribution modeling indicates that, under a temperature increase of 3ºC, four reptile species could lose half or more of their area of suitable climate in the park: Blainville's horned lizard (*Phrynosoma blainvillii*), desert spiny lizard (*Sceloporus magister*), night lizards (*Xantusia spp.*), and the northwestern fence lizard (*Sceloporus occidentalis*) (Barrows et al. 2014). One species, the northern desert iguana (*Dipsosaurus dorsalis*), could lose one-third of its suitable climate in the park. Two other species could possibly gain some area of suitable climate: northern desert horned lizard (*Phrynosoma platyrhinos*) and the common chuckwalla (*Sauromalus ater*). A similar analysis also found that desert spiny lizard (*Sceloporus magister*), northwestern fence lizard (*Sceloporus occidentalis*), and the southern sagebrush lizard (*Sceloporus vandenburgianus*) could lose one-half of their suitable climate in the park and that granite spiny lizard (*Sceloporus* orcutti) could lose one-third (Barrows and Fisher 2014). Limiting the temperature increase to 1ºC could limit the loss of suitable climate to one-tenth to one-fifth (Barrows and Fisher 2014). For the common chuckwalla, species distribution modeling that added a rainfall decrease of 75 mm to the temperature increase of 3ºC indicated a potential habitat loss of three-quarters (Barrows 2011), opposite of the result from modeling just the temperature increase (Barrows et al. 2014).

Western monarch butterflies The western population of monarch butterflies (*Danaus plexippus*) breeds in the summer in northern California and the Sierra Nevada and migrates for the winter to southern California, passing through Joshua Tree National Park. Western monarch abundance has declined in breeding areas from 1972 to 2014 and in overwintering areas from 1997 to 2014 (Espeset et al. 2016). Analyses of climate data indicate that climate change, however, is not more important than habitat loss and pesticide use (Espeset et al. 2016).

Bird range changes Climate change could continue to shift ranges of bird species northward across the US (Langham et al. 2015). Modeling of suitable climate for bird species in 2050 indicates that, under the highest emissions scenario (RCP8.5), the park and a 10 km wide area around the park may gain suitable climate for 50 bird species not currently present in winter and eight species not currently present in summer but lose suitable climate for 11 species in winter and 10 species in summer (Wu et al. 2018). Potential colonizers include the crested caracara (*Caracara cheriway*) and the cave swallow (*Petrochelidon fulva*). Species vulnerable to disappearance include the golden-crowned sparrow (*Zonotrichia atricapilla*) and violet-green swallow (*Tachycineta thalassina*) (Wu et al. 2018).

Detailed research on the yellow-billed cuckoo (*Coccyzus americanus*) (Friggens and Finch 2015, Wallace et al. 2013, Anders and Post 2006) and Lucy's warbler (*Oreothlypis luciae*) (Friggens and Finch 2015) indicated a sensitivity to heat and drought that could lead to range contractions under climate change. In addition, researchers observed that the yellow-billed cuckoo expresses a phenological preference for woodland areas that experience peak greenness later than average for an area (Wallace et al. 2013).

Desert bighorn sheep Climate change increases the risk of habitat loss for desert bighorn sheep (*Ovis canadensis nelsoni*) at low elevations and genetic isolation at high elevations in the Mojave and Sonoran Deserts, including in the San Bernardino and the Pinto Mountains in Joshua Tree National Park (Epps et al. 2006, 2007).

Health and Safety of Visitors and Staff

Extreme heat Exposure to hotter temperatures in heat waves has led to deaths due to heat stroke and other illnesses- in the past in California (Knowlton et al. 2009, Hoshiko et al. 2010, Guirguis et al. 2014). Under continued climate change, projected increases in hot days and extreme heat events, up to 40 more days per year with a maximum temperature >32ºC (90ºF.) in the region around the park under the highest emissions scenario (RCP8.5) (Vose et al. 2017), will increase the risk of heat-associated death (USGCRP 2016).

Surface ozone pollution The formation of ground-level ozone, a pollutant hazardous to people, increases as temperature increases. Under low emissions (RCP4.5), the number of episodes in the region of the park with ground-level ozone >75 parts per billion could increase up to six days by 2050 (Shen et al. 2016).

Dust storms Under the highest emissions scenario (RCP8.5), modeling of dust storms projects a potential 3% increase of frequency in Jun, July, and August north of the park (Pu and Ginoux 2017) and shifting of dust storm occurrence to earlier in the year (Hand et al. 2016). Projected increases of dust storms in the southwestern US due to climate change could increase respiratory diseases (Schweitzer et al. 2018), cardio-vascular diseases (Achakulwisut et al. 2018), Rift Valley Fever (Tong et al. 2017, Gorris et al. 2018), and total deaths of people from dust-associated health problems (Crooks et al. 2016, Achakulwisut et al. 2018).

Flash floods Whether total annual precipitation in the region of the park decreases or increases in the future, GCMs project up to a doubling of extreme storm frequency and a potential increase in the average amount of precipitation in a storm (Easterling et al. 2017). Hydrological modeling of small watersheds along the southern California mountain ranges, including the San Bernardino Mountains west of the park, project an increase in flash flood frequency of 30 to 40% (Modrick and Georgakakos 2015). The projections indicated fewer storms, but higher rainfall intensity over soils with higher initial soil moisture saturation, leading to the projected increase in the frequency of flash floods.

Cultural Resources

Joshua Tree National Park protects archaeological and historical sites and artifacts of the native Serrano, Chemeuevi, and Cahuilla native peoples and 19th and 20th century mining and ranching settlers. Experience from other parts of the world has identified numerous risks of cultural resources to climate change (Harvey and Perry 2015). While no published research has examined the climate change risks to cultural resources specific to Joshua Tree National Park, climate projections for the park suggest exposure to potentially damaging conditions. Increases in fire could damage any wooden artifacts or components of historic structures. Increased aridity could increase the vulnerability of palm oases to desiccation or fire. Those changes and changes in vegetation composition could alter traditional cultural properties, ethnographic resources, and cultural landscapes.

Carbon

Growing vegetation naturally removes carbon from the atmosphere, reducing the magnitude of climate change. Conversely, tree mortality, from deforestation, wildfire, drought, and other causes, emits carbon to the atmosphere, exacerbating climate change. The balance between carbon emissions from vegetation to the atmosphere and removals from the atmosphere into vegetation determines the role of ecosystems in climate change (IPCC 2013).

Analyses of Landsat remote sensing at 30 m spatial resolution, field measurements of biomass, and Monte Carlo analyses of error in tree measurements, remote sensing, and the carbon fraction of biomass determined this balance across the state of California (Gonzalez et al. 2015). In 2010, aboveground live vegetation in Joshua Tree National Park contained 140 000 ± 200 000 tons of carbon (mean ± 95% confidence interval) (Gonzalez et al. 2015). This is equivalent to one year of carbon emissions from 24 000 people in the US. The highest carbon density in the park occurs in areas with California juniper (*Juniperus californica*) and singleleaf pinyon (*Pinus monophylla*) trees (Figure 12). Desert ecosystems generally contain carbon at densities lower than most ecosystems. From 2001 to 2010, the carbon stock in the aboveground vegetation of the park increased 14 ± 18% (Figure 13), but the change was not statistically significant (Gonzalez et al. 2015).

As part of the NPS Climate Friendly Parks program, Joshua Tree National Park has conducted an inventory of greenhouse gas emissions from fossil fuel use in energy, transportation, and waste generation by park operations and visitors (NPS 2010). The analysis estimated total emissions in 2008 of 1800 tons of carbon, of which 89% came from cars and other vehicles of staff and visitors, 3% from waste that went to landfills, and 2% from electricity use. The *Joshua Tree National Park Action Plan* (NPS 2010) identified renewable energy, energy conservation, and other actions to cut the emissions that cause climate change. In 2018, the park and the Morongo Basin Transit Authority started the RoadRunner shuttle bus through the most highly visited areas of the park, which could potentially reduce a portion of the greenhouse gas emissions in the park by taking cars off the road. The Intergovernmental Panel on Climate Change has recently confirmed that concerted global action can reduce emissions enough to meet the Paris Agreement goal of limiting future global temperature increase to 1.5 to 2ºC (IPCC

2018). The difference between the emissions reductions scenario (RCP2.6) and the worst-case scenario (RCP8.5), as shown in Tables 3 and 4 and much of the research cited in this report, shows that emissions reductions can substantially reduce the future heating of the park and risks to its plants, animals, and unique ecosystems.

Acknowledgements

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Figure 1. Joshua Tree National Park and surrounding area, including the City of Palm Springs and Mount San Jacinto, covered by clouds, to the southwest. Natural color satellite image, April 30, 2019 (data U.S. Geological Survey, analysis P. Gonzalez).

Figure 2. Average annual temperature for the area within park boundaries, 1895-2016, (Gonzalez et al. 2018) and at the weather station in Twentynine Palms, 1936-2017 (https://www.ncdc.noaa.gov/cdo-web/datasets/GSOM/stations/GHCND:USC00049099/detail).

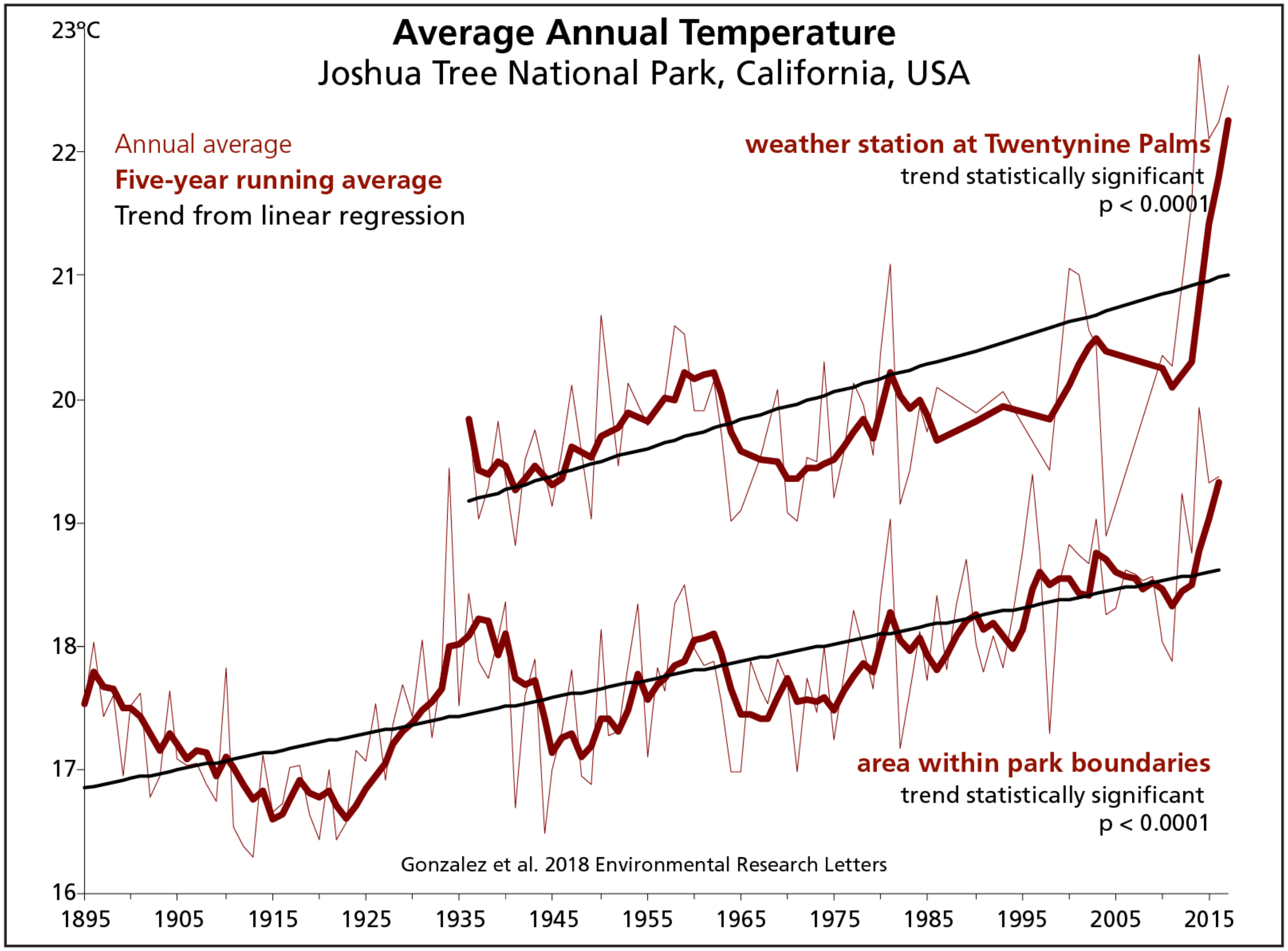

Figure 3. Monthly average temperatures, historical and projected, for the area within park boundaries (Gonzalez et al. 2018). From 1895 to 2010, the period of temperatures above 27ºC (81ºF.) increased from zero to six weeks. Under the highest emissions scenario, climate change could lengthen the period of temperatures above 28ºC from zero to three months by 2100. Cutting carbon emissions from human activities could reduce the increase in the warm period by two-thirds.

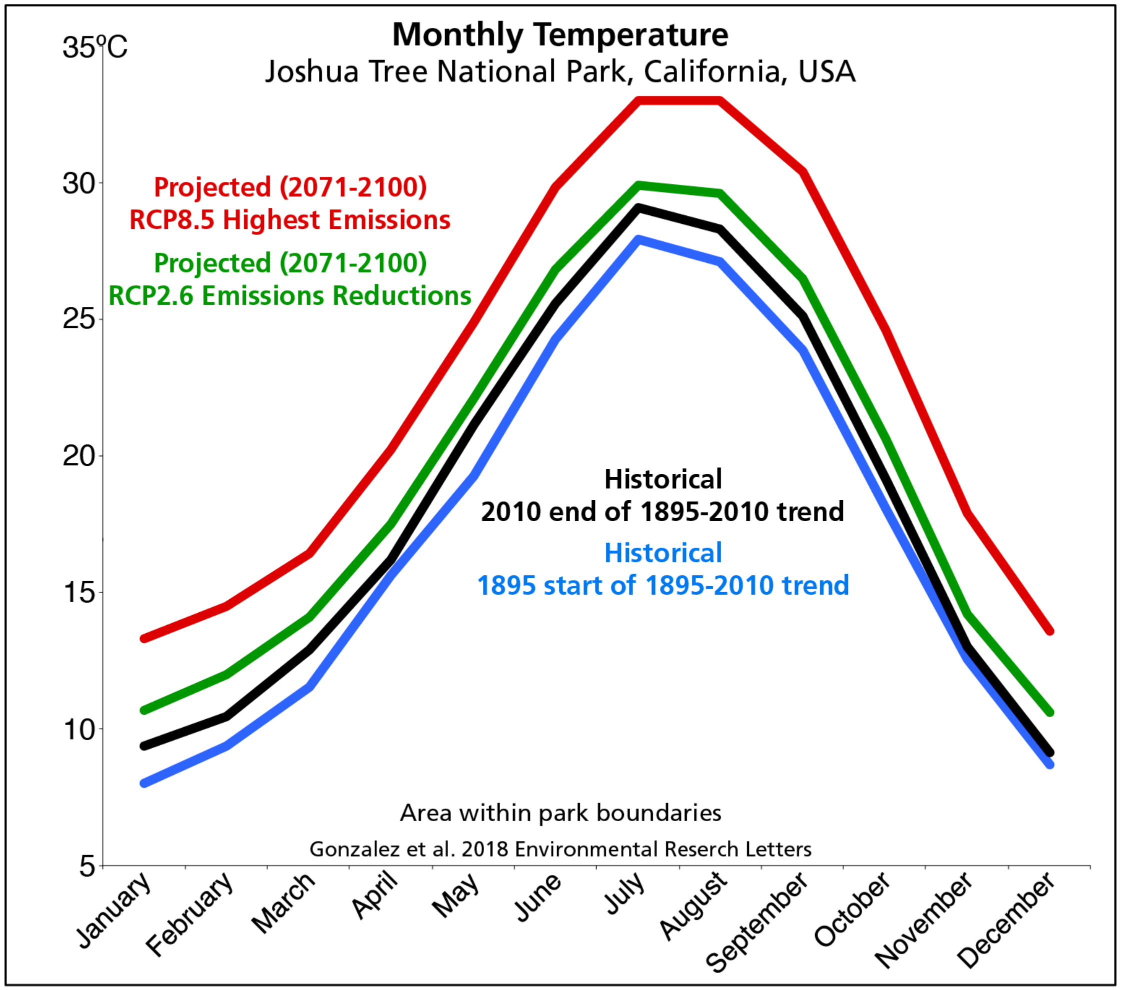

Figure 4. Trend in annual average temperature, 1895-2016, at 800 m spatial resolution, from linear regression, corrected for temporal autocorrelation (Gonzalez et al. 2018).

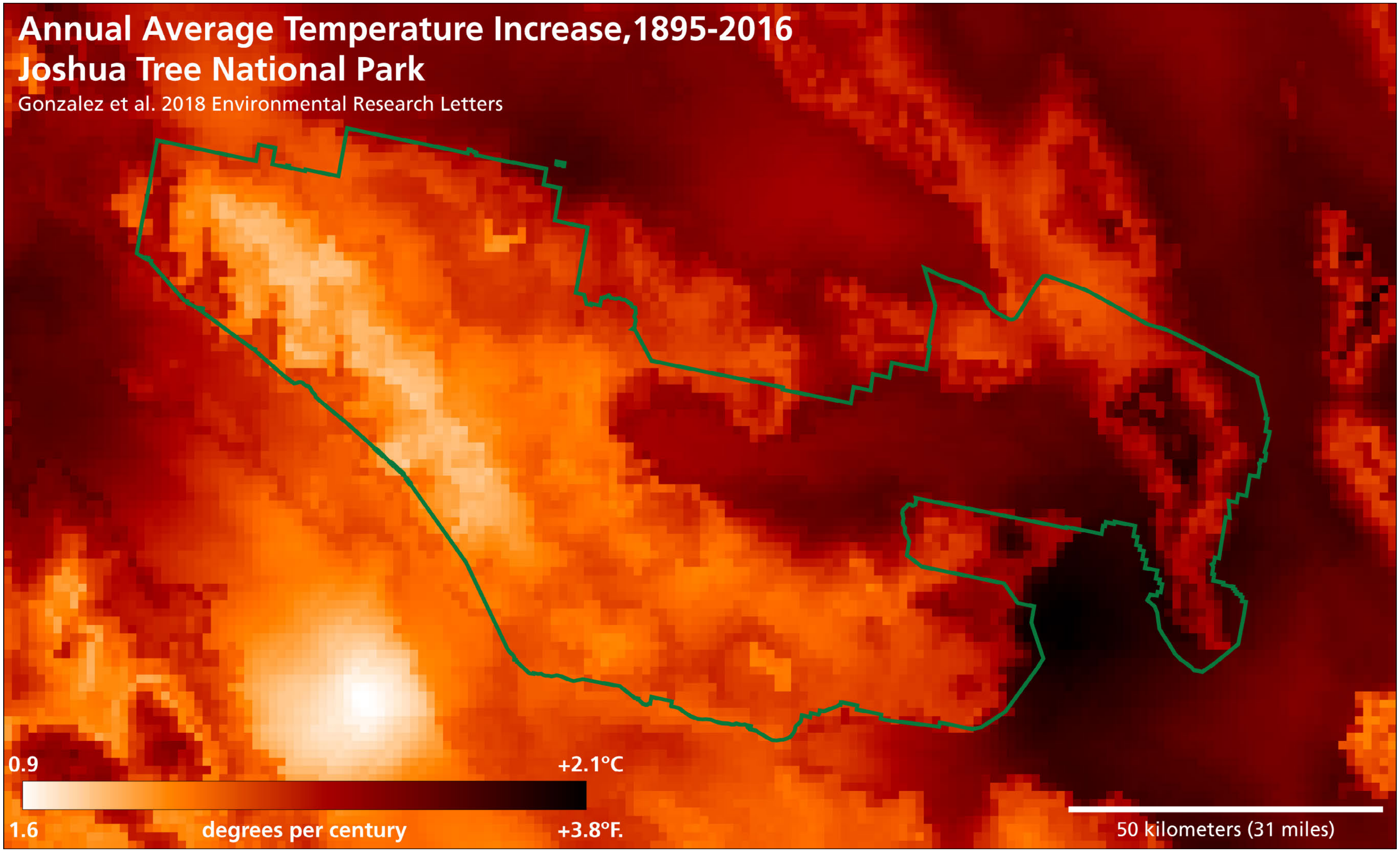

Figure 5. Total annual precipitation for the area within park boundaries, 1895-2016, (Gonzalez et al. 2018) and at the weather station in Twentynine Palms, 1936-2017 (https://www.ncdc.noaa.gov/cdo-web/datasets/GSOM/stations/GHCND:USC00049099/detail).

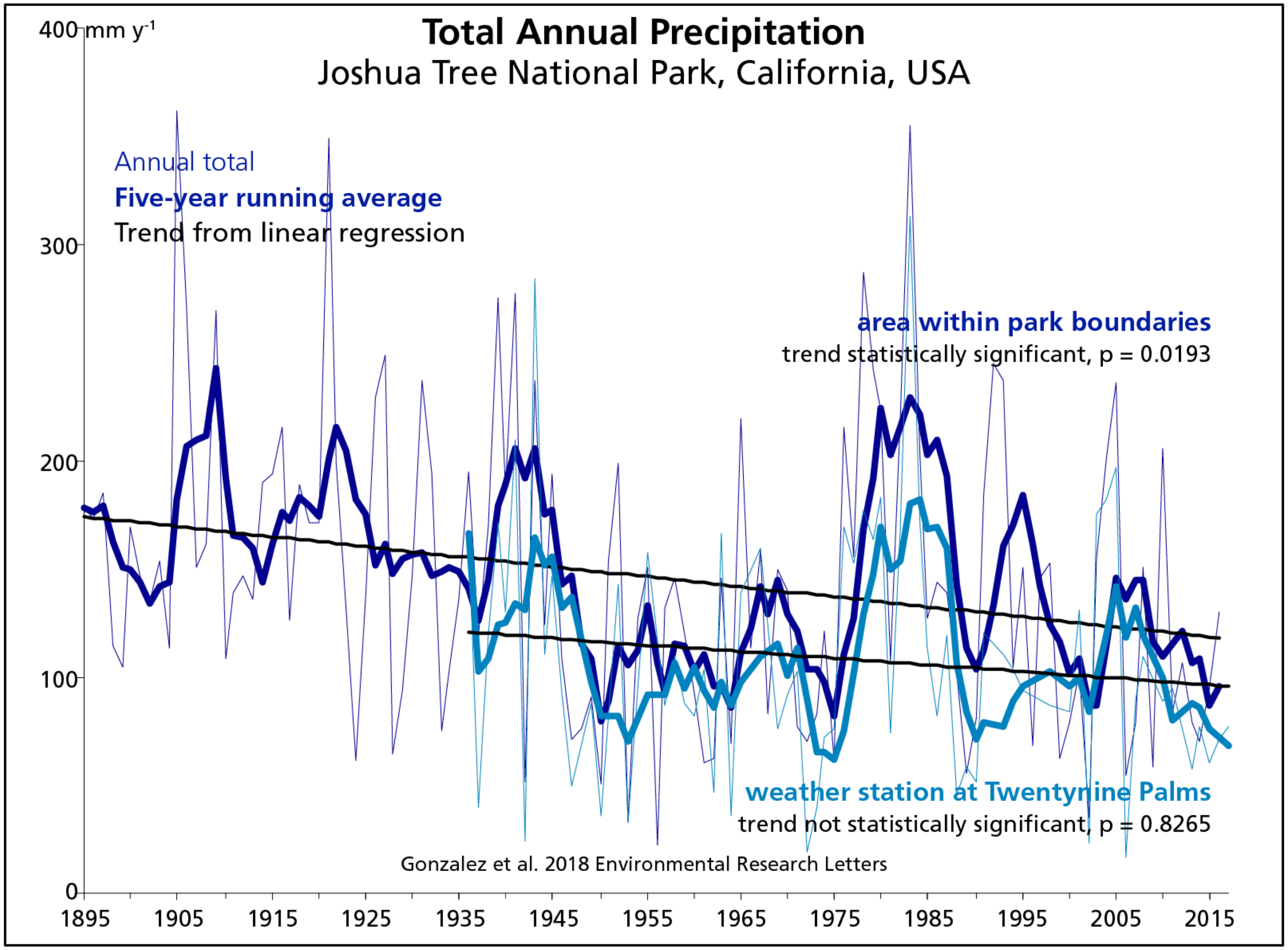

Figure 6. Trend in total annual precipitation, 1895-2016, at 800 m spatial resolution, from linear regression, corrected for temporal autocorrelation (Gonzalez et al. 2018).

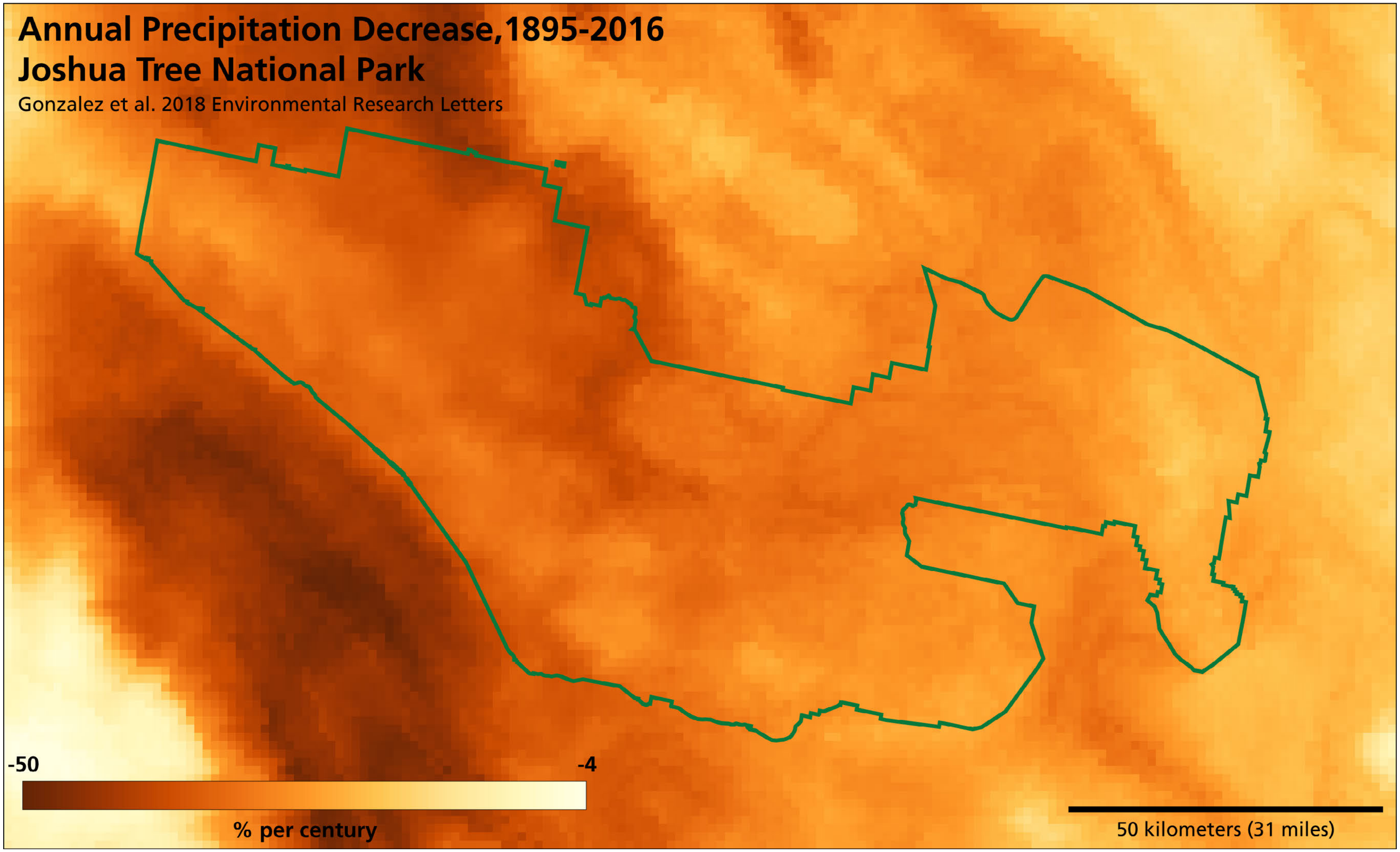

Figure 7. Projections of future climate for the area within park boundaries, relative to 1971-2000 average values (Gonzalez et al. 2018). Each small dot is the output of one of 121 general circulation models. The large color dots are the average values for the four IPCC emissions scenarios. The crosses are the standard deviations of the average values.

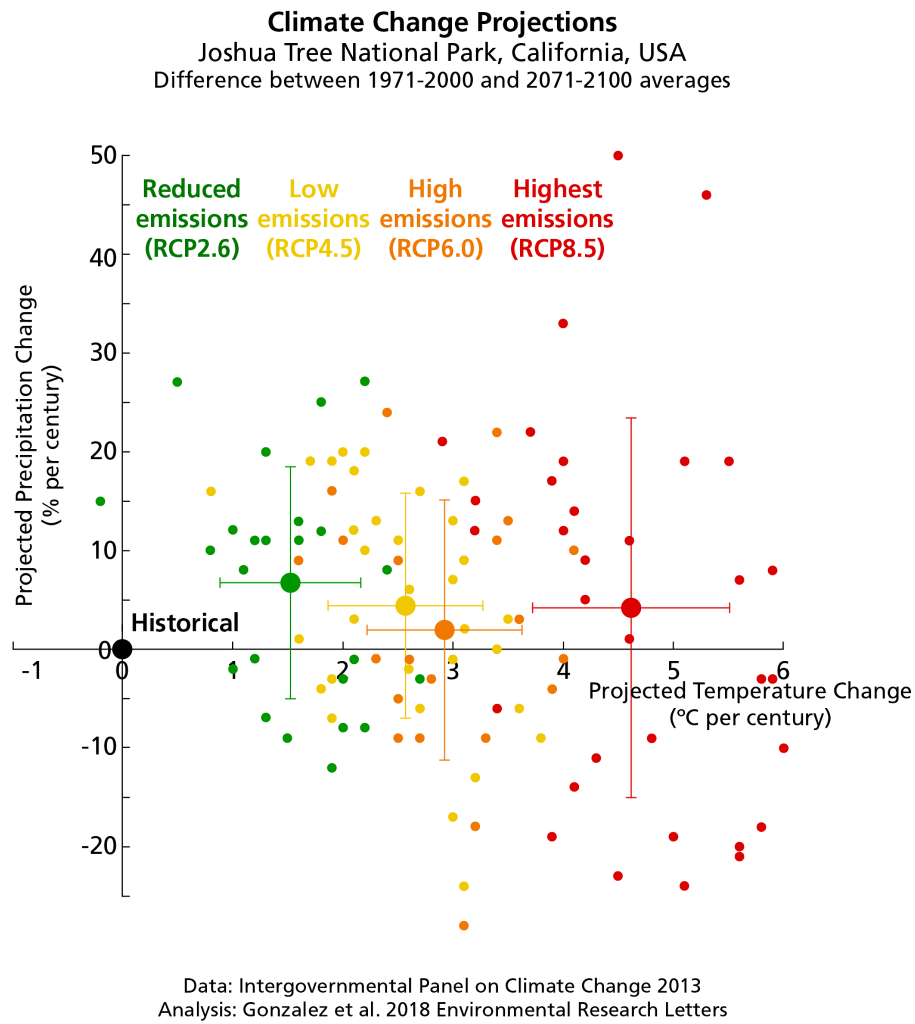

Figure 8. Projected change in annual average temperature, 2000-2100, at 800 m spatial resolution, for the highest emissions scenario (RCP8.5) for the average of 33 general circulation models (IPCC 2013, Gonzalez et al. 2018).

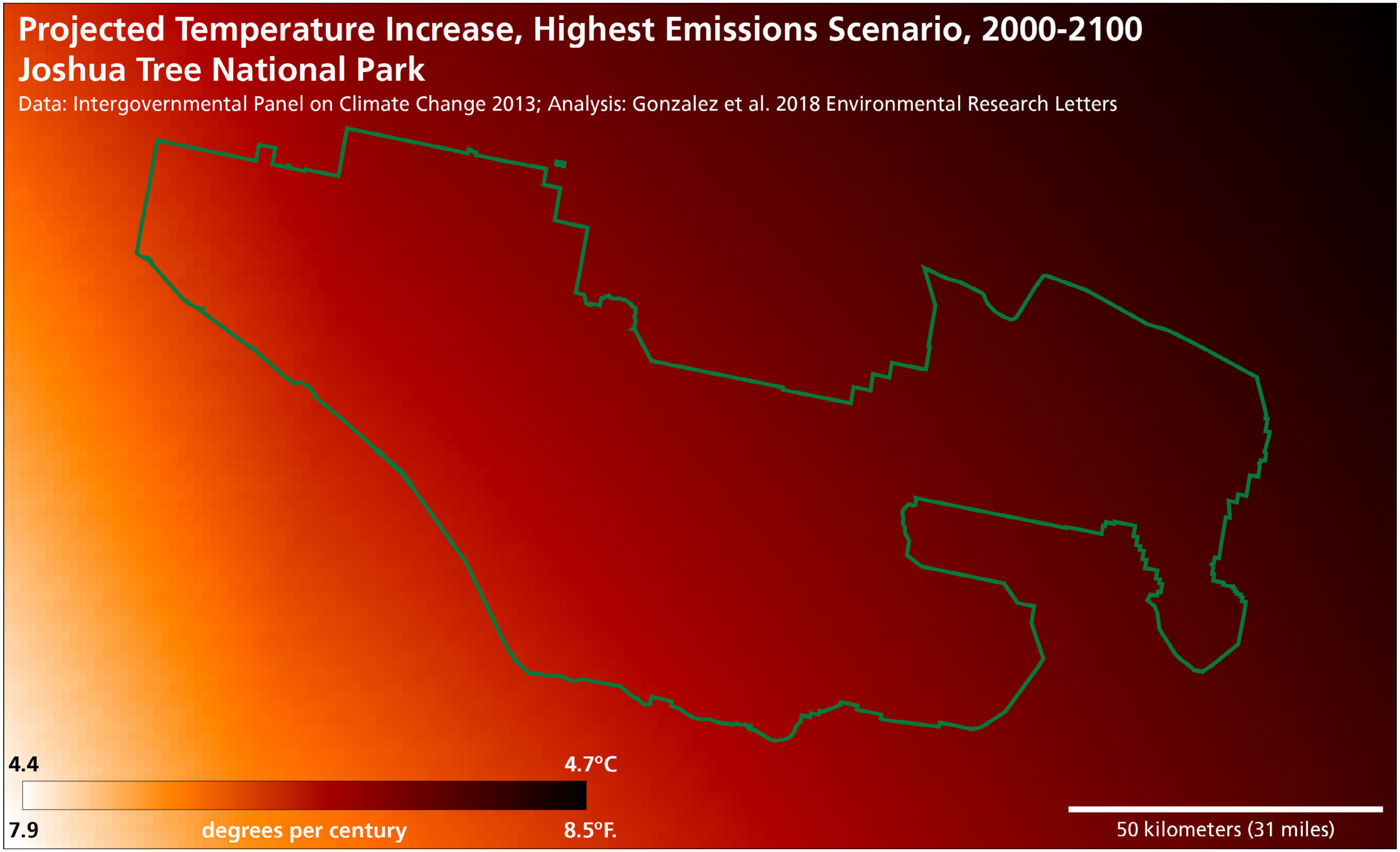

Figure 9. Projected change in total annual precipitation, 2000-2100, at 800 m spatial resolution, for the highest emissions scenario (RCP8.5) for the average of 33 general circulation models (IPCC 2013, Gonzalez et al. 2018).

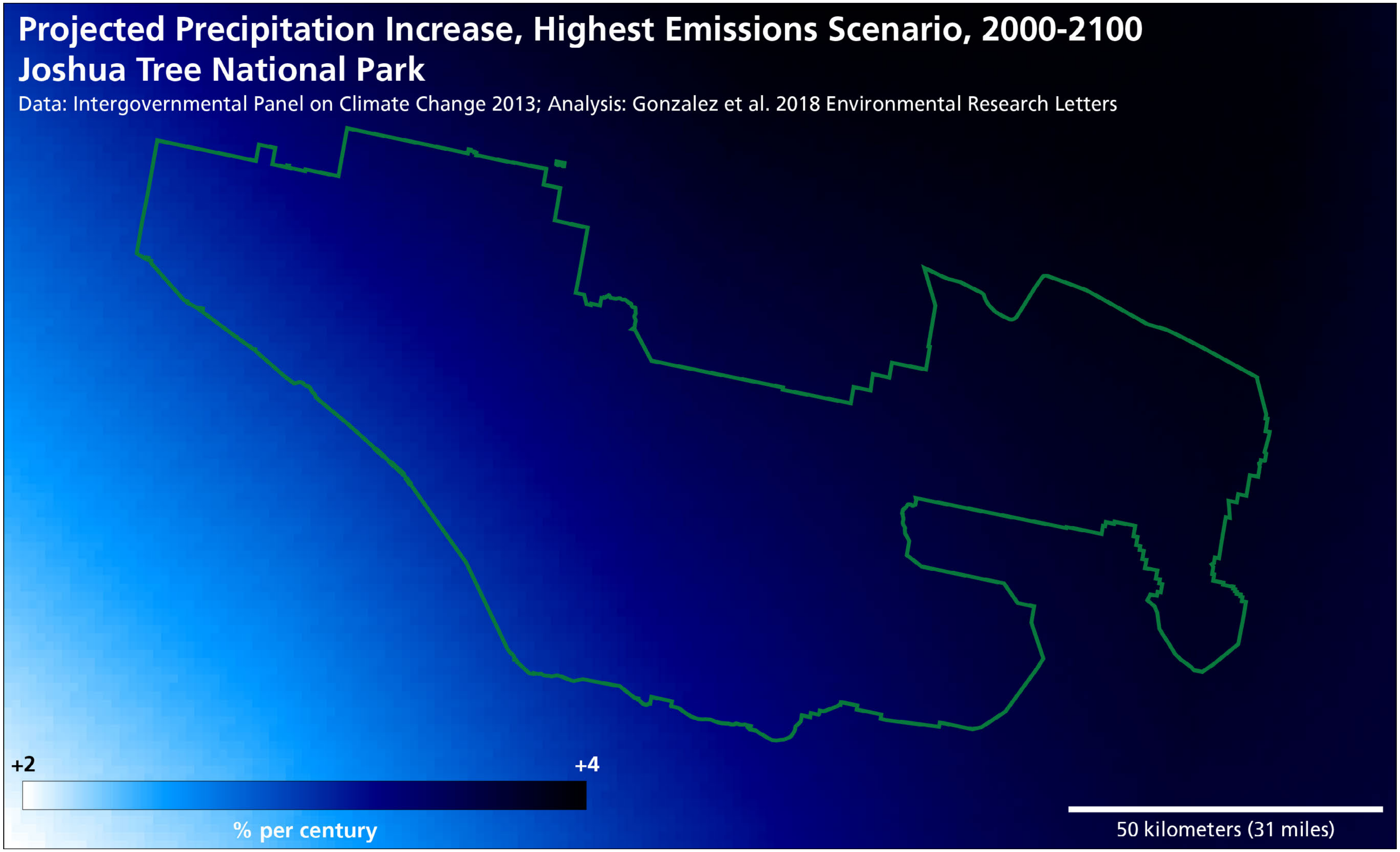

Figure 10. Modeled suitable habitat of Joshua trees in Joshua Tree National Park (Sweet et al. 2019). (a) Historical 1951-1980, (b) Projected 2070-2099, low emissions (RCP4.5), (c) Projected 2070-2099, high emissions (RCP6.0), (d) Projected 2070-2099, highest emissions (RCP8.5), based on the output of one general circulation model.

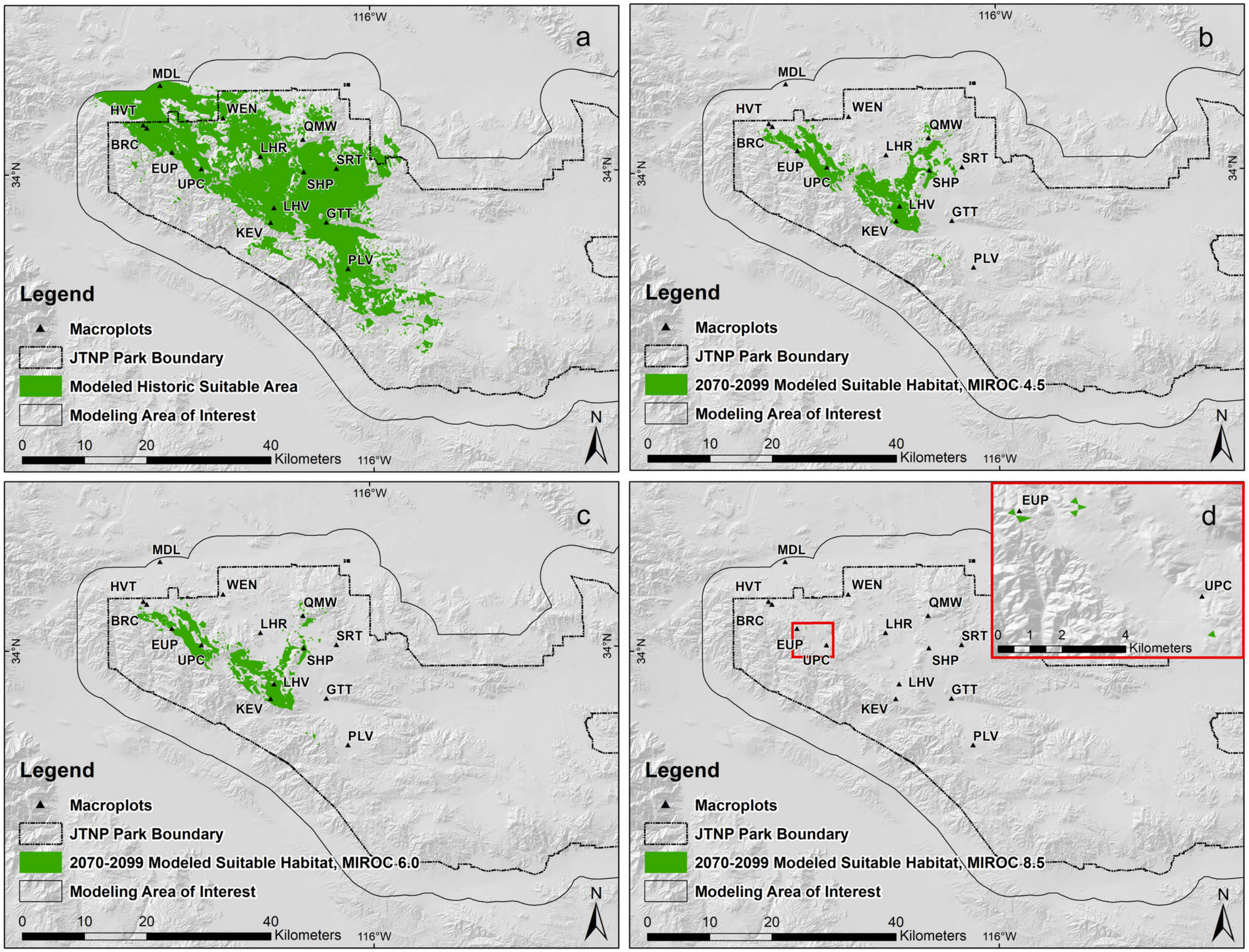

Figure 11. Modeled change of suitable climate for Joshua trees across the southwestern US under a medium emissions scenario (A1B, IPCC (2001), between RCP4.5 and RCP6.0 (IPCC 2013)) between the periods 1930-1969 and 2070-2099 based on the output of five general circulation models at 4 km spatial resolution (Cole et al. 2011).

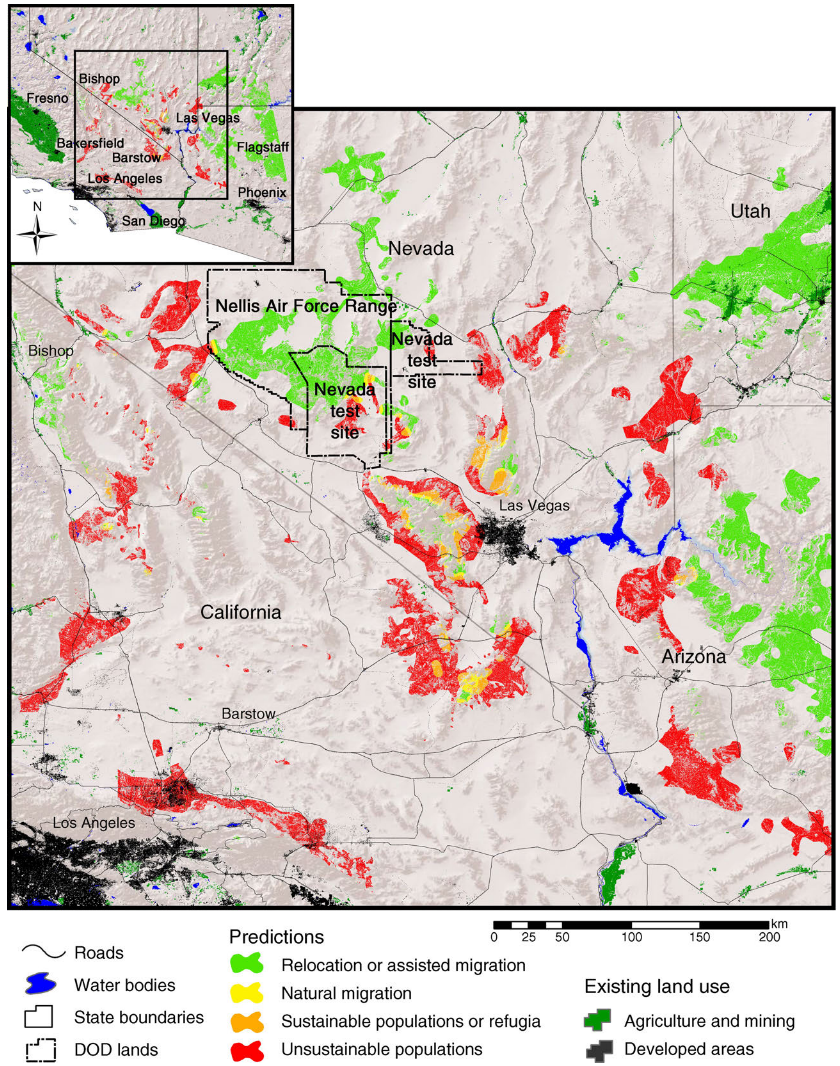

Figure 12. Carbon in aboveground live vegetation in 2010 (Gonzalez et al. 2015).

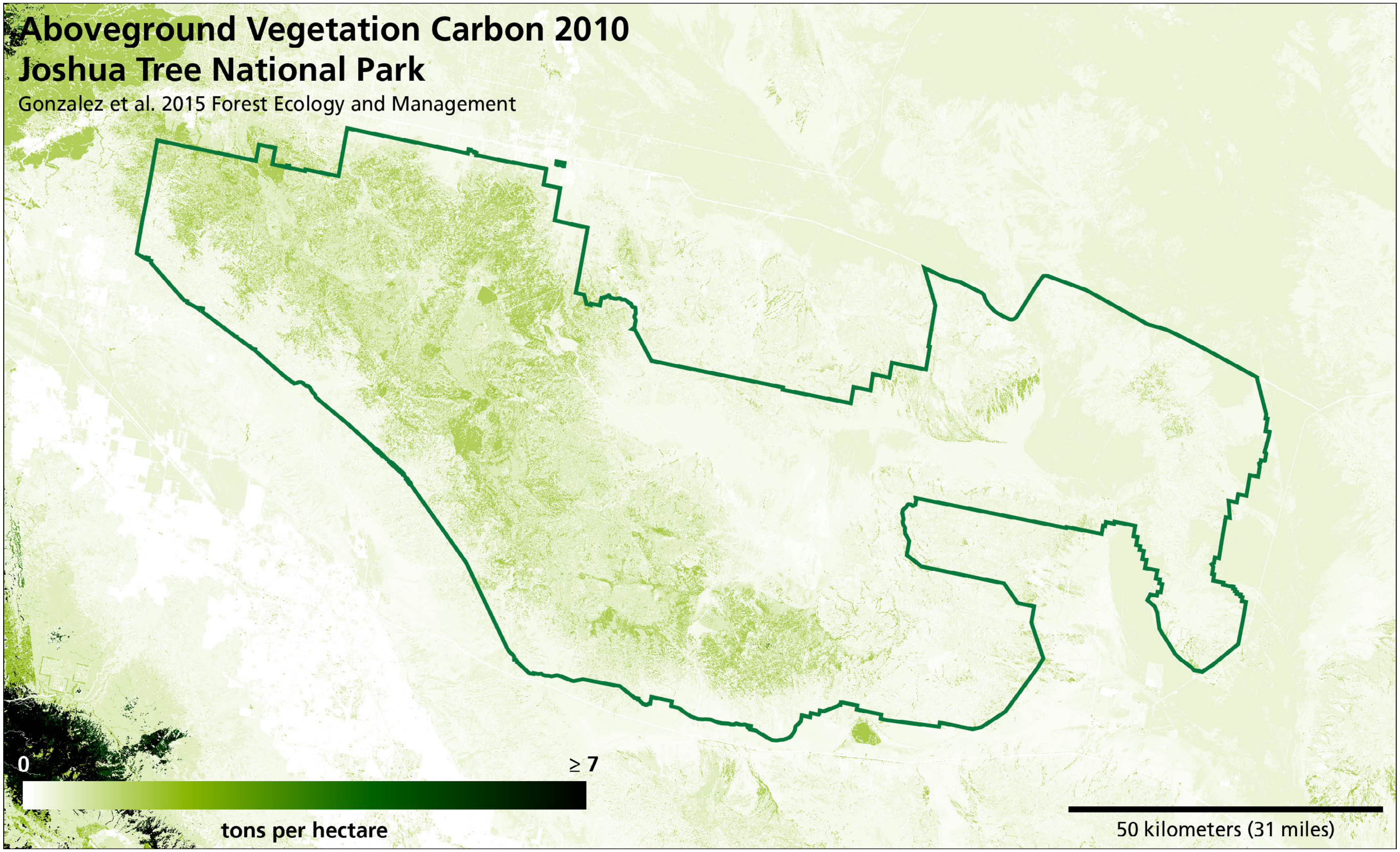

Figure 13. Change in carbon in aboveground live vegetation, 2001-2010 (Gonzalez et al. 2015).

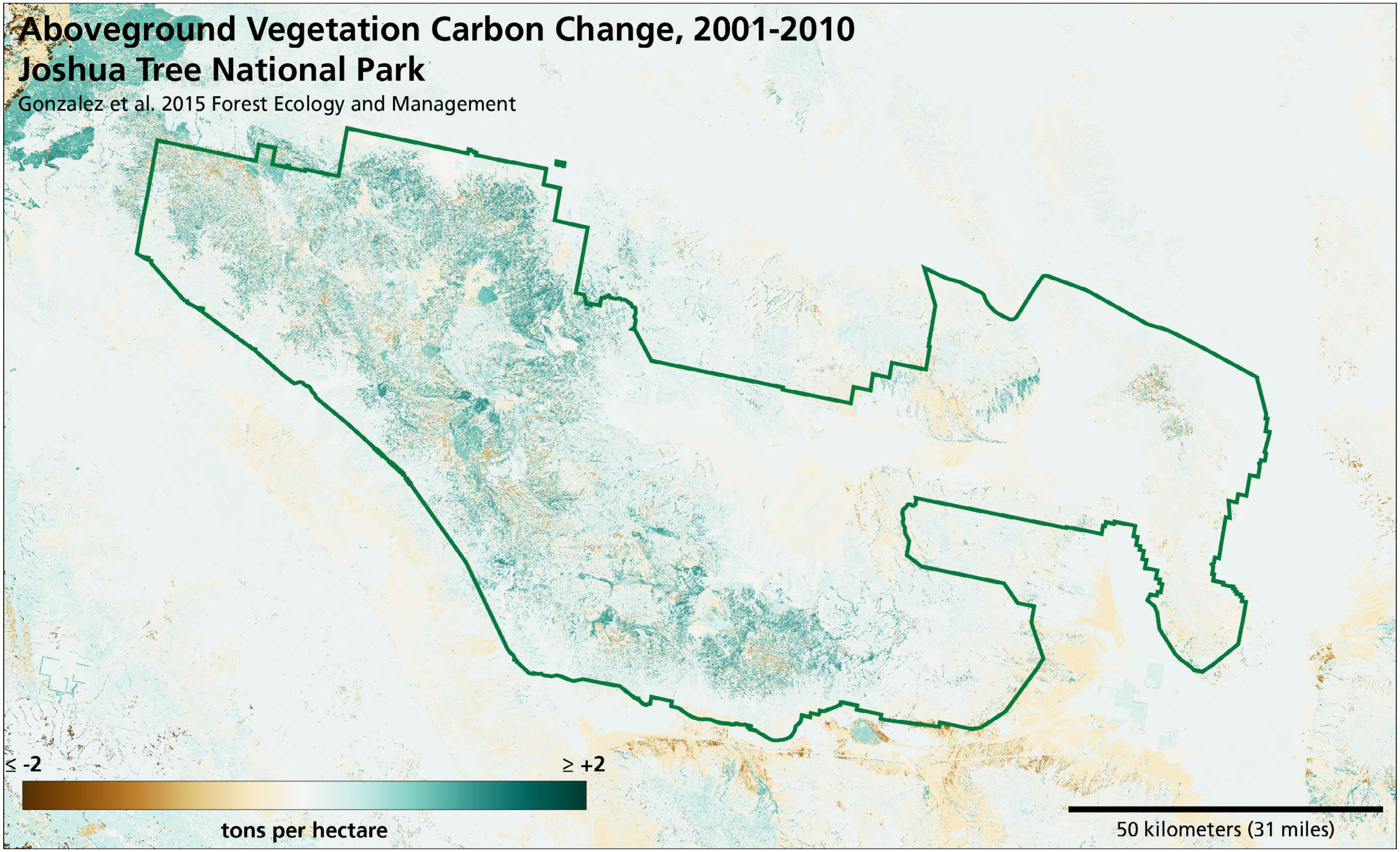

Table 1. **Historical average temperatures** and trends for the area within the boundaries of Joshua Tree National Park (Gonzalez et al. 2018). SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century^{-1}			°C century^{-1}		
Annual	18	0.5	0.9	0.2	***	1.5	0.5	**
December-February	9.6	1.1	0.8	0.3	**	0.8	0.6	
March-May	16.5	1.4	1.1	0.3	**	2.8	0.9	**
June-August	27.3	0.7	1	0.3	***	2.1	0.7	**
September-November	18.7	1	0.8	0.3	**	0.5	0.7	
January	9.2	1.4	1.2	0.4	**	2.8	1	**
February	10.6	1.4	0.9	0.4	*	0.5	0.9	
March	12.6	1.8	1.2	0.5	*	3.5	1.3	**
April	16.2	1.9	0.5	0.5		1.1	1.3	
May	20.6	1.8	1.6	0.4	***	3.7	1.1	***
June	25.4	1.3	1.1	0.5	*	2.7	1.3	*
July	28.5	1	1	0.3	**	1.7	0.9	
August	27.9	1	1	0.3	**	2	0.8	*
September	24.7	1.3	1.1	0.4	**	0.9	1	
October	18.8	1.5	0.9	0.4	*	-0.7	1.2	
November	12.7	1.5	0.4	0.4		1.1	1.1	
December	9.1	1.7	0.4	0.4		-0.9	1.2	

Table 2. **Historical average precipitation** totals and trends for the area within the boundaries of Joshua Tree National Park (Gonzalez et al. 2018). No trends were statistically significant. SD = standard deviation, SE = standard error.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	mm y^{-1}		% $century^{-1}$			% $century^{-1}$		
Annual	174	83	-7	15		48	45	
December-February	83	66	2	19		118	58	
March-May	31	25	-19	26		21	74	
June-August	32	34	-22	25		-44	76	
September-November	28	29	-6	22		-33	61	
January	32	37	-1	30		86	77	
February	33	33	11	30		197	81	*
March	24	24	-6	34		60	98	
April	4	5	-45	41		-75	85	
May	3	3	-58	40		-79	99	
June	1	1	-138	59		-107	153	
July	11	15	-26	29		-60	89	
August	21	27	-14	28		-33	85	
September	12	23	-15	55		-41	136	
October	7	8	-7	35		45	102	
November	9	11	2	31		-76	90	
December	18	19	-1	28		83	76	

Table 3. **Projected temperature increases** (°C), 2000 to 2100, for the area within the boundaries of Joshua Tree National Park (Gonzalez et al. 2018), from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.5	0.6	2.6	0.7	2.9	0.7	4.6	0.9
December-February	1.5	0.6	2.3	0.7	2.7	0.7	4.1	1
March-May	1.4	0.6	2.2	0.9	2.7	0.7	4.1	0.9
June-August	1.5	0.9	2.6	0.9	3	0.8	4.7	1
September-November	1.7	0.8	3.2	1.5	3.4	0.9	5.6	1.8
January	1.5	0.7	2.3	0.7	2.7	0.8	4.1	0.9
February	1.4	0.6	2.1	0.8	2.6	0.7	3.9	0.9
March	1.5	0.7	2.1	0.8	2.6	0.7	3.8	1
April	1.3	0.6	2.1	0.9	2.6	0.7	4	1
May	1.5	0.6	2.5	1.1	2.9	0.8	4.3	1.1
June	1.4	0.8	2.3	1.2	2.8	0.8	4.4	1.2
July	1.4	0.9	2.4	0.9	2.8	0.9	4.5	1.1
August	1.7	1	2.9	0.9	3.4	0.9	5.1	1.2
September	1.8	0.9	3.3	1.2	3.5	1	5.7	1.5
October	1.8	0.9	3.3	1.7	3.4	1	5.8	1.9
November	1.5	0.8	3	1.9	3.2	0.9	5.2	2.2
December	1.5	0.6	2.5	1.4	2.7	0.9	4.5	1.7

Table 4. **Projected precipitation changes** (%), 2000 to 2100, for the area within the boundaries of Joshua Tree National Park (Gonzalez et al. 2018), from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	7	11	4	11	2	13	4	19
December-February	4	21	9	24	7	31	14	40
March-May	5	22	-10	21	-14	18	-21	27
June-August	10	29	14	34	8	31	14	49
September-November	15	22	9	29	3	23	7	24
January	12	34	17	35	20	49	27	58
February	2	28	10	32	-1	34	14	45
March	3	31	-7	28	-7	26	-13	31
April	14	44	-12	32	-20	31	-31	36
May	10	53	-15	40	-28	31	-41	39
June	7	61	17	71	7	74	0	62
July	18	45	22	58	17	42	28	72
August	8	31	12	37	4	31	10	52
September	42	67	21	53	26	69	28	54
October	21	40	17	48	23	48	22	54
November	-2	22	-2	41	-19	21	-13	37
December	-2	22	-6	26	2	30	-2	35

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